The Shuttle Continuum, Role of Human Spaceflight

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President George H.W. Bush

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Elementary school teachers

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Canadian Space Agency

General John Dailey
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The theme of this book is the scientific and engineering accomplishments of the Space Shuttle Program. The end of this longest-running human spaceflight program marks the end of an era for our nation. At this juncture, it is natural to ask: Why human spaceflight? What is the future of human spaceflight? What space exploration initiatives should we engage in, in the future?

The editor in chief of this publication invited some noted leaders from the government and industry, educators, students, and others to share their views and thoughts on these questions. Each contributor provided his or her own unique perspective. The editors are pleased and grateful for their contribution.

GEORGE BUSH

First and foremost, I am pleased to contribute a few words to this worthwhile project on the legacy of the Space Shuttle program because of my respect for the remarkable men and women who have shaped the program, and led it, and made it one of the most vital forces for scientific discovery and progress in our world.

To me, there are few public endeavors that best exemplify the American spirit of innovation and daring than does our Space Shuttle program. Like the manned space flight programs that preceded it — indeed, as was the case with each and every explorer throughout the ages — the Americans leading the Shuttle program yesterday, today, and tomorrow are drawn to challenge. They seek to push back the horizon of discovery. And, yes, maybe as creator Gene Roddenberry of *Star Trek* fame suggested, they also seek to "go boldly where no man has gone before."

Was it not the same spirit that inspired the pioneers of old to take to the ancient spice trails of Asia, or to alight from the ports of medieval Europe for the highly uncertain journey ahead?

Just as important to me is the way NASA and our government has opened our Shuttle and Space Station program to our partners and allies across the world, to ensure that the exploration of space benefits not just America — but mankind as a whole.

This, then, is the essence of American leadership, your leadership, that today is expanding our scientific awareness even as it brings our world closer together.

President Kennedy was right: we do these things not because they are easy, but because they are hard. But because they are hard, and because you continue to persevere and succeed, and because, furthermore, you succeed based on the values that have always made America a force for goodness and progress in our world, you also help to continue inspiring our world and capturing our imagination.

So to the heirs of our manned space program, keep up the wonderful work. Keep pushing back that horizon, and boldly seeking new places to go. And in the process, help us to keep setting higher standards for the kinds of scientific research and courageous exploration that make this a better world than we found it. Succeeding generations of Americans have blessed us in such a manner; now it is your time to answer the call.

May God bless you all, and our United States.

George Bush

Inspiring Students Through Human Spaceflight

Pam Leestma and Neme Alperstein

Pam Leestma taught elementary school for 30 years at Valley Christian Elementary School, Bellflower, California. She won the 2008 National American Star Teaching Award.

Neme Alperstein taught for 22 years at the Harry Eichler School, a New York City public school. She was the New York City Teacher of the Year in 2000.

Neil Armstrong's "one small step for man, one giant leap for mankind" changed the course of history in our quest to explore space. "Failure is not an option" was the Apollo Program's vision to inspire the nation and is the space agency's legacy for the next generation.

Today we are a global community with international space partners exploring a new frontier filled with imagination and innovation. Scientific discoveries, human spaceflight, space tourism, moon colonies, and the exploration of Mars and beyond will be the vehicles that will continue to find common ground for transcending borders through understanding, respect, friendship, and peace.

NASA's education programs have provided the powerful resources to engage young minds. Their essential 21st century tools have brought our youth closer to those on the frontier of exploration through numerous multimedia interactive technologies. Some ways that we, as educators, have been able to get our students "up close and personal" with NASA include speaking with an astronaut aboard the International Space Station in real time (a downlink), using the facilities of a local California city hall and a New York City community center for a NASA first coast-to-coast downlink, videoconferencing with NASA's Digital Learning Network experts and astronauts living and training under water off the Florida coast (NASA's Extreme Environment Missions Operations), growing basil seeds flown in space with astronaut and educator Barbara Morgan, participating in NASA's live webcasts, watching NASA TV during coverage of Space Shuttle launches and landings, and organizing stargazing family nights for the school community. The impact of these extraordinary experiences has been life changing.

The unimaginable has become the world of infinite possibilities in science, technology, engineering, and mathematics. Human spaceflight missions reflect the diversity of our global community and the best that such collaboration offers mankind. This diversity reaches out to all students who see increased opportunities for participation. They see the potential to create the next generation of "spinoffs" that will improve daily life

as a result of NASA research and development. They include medical breakthroughs, the development of robotics in exploration and in everyday life, materials science in the creation of materials with new properties (i.e., spacesuits), researching the effect of extreme environments, and the quest for cures and developing new medicines in microgravity.

NASA continues to support teachers through its professional development, conferences, workshops, content across the curriculum, and its willingness to provide access to its scientific community and experts. We never cease to be amazed by NASA's generosity of spirit ever present at the Space Exploration Educators Conference we always attend. Teachers return to their classrooms inspired. It's a ripple effect.

NASA's vision has provided the spark that ignites the excitement and wonder of exploration and discovery. Our students see themselves as the next explorers of this new frontier. It is an imperative that we continue human spaceflight if for no other reason than to improve life here on Earth and foster cooperation within the global community. Space exploration offers our children hope for the future.

What's Next for Human Spaceflight?

Norman Augustine
Former president and CEO of Lockheed Martin Corporation and recipient of many honors for his national defense, homeland security, and science policy accomplishments.

Parachuting an instrument package onto the summit of Mt. Everest would, without question, have been a significant and exciting scientific contribution. But would it have had the broad impact of Sir Edmund Hillary and Tenzing Norgay standing atop the 29,035 ft peak?

There are many important missions that can and should be accomplished with robotic spacecraft, but when it comes to inspiring a nation, motivating young would-be scientists and engineers and adaptively exploring new frontiers, there is nothing like a human presence. But humans best serve a nation's space goals when employed not as truck drivers but rather when they have the opportunity to exploit that marvelous human trait: flexibility. A prime example is the on-orbit repair of the Hubble Space Telescope using the shuttle. Without that capability for in situ human intervention, Hubble, itself a monumental accomplishment, would have been judged a failure. Indeed, there are important missions for both humans and robots in space—but each is at its best when it does not try to invade the other's territory.

So what is next for human spaceflight? There is a whole spectrum of interesting possibilities that range from exploring Mars, Demos, or Phoebus, to establishing a station on the moon or at a neutral gravity point. It would seem that the 1990 recommendations of the White House/NASA commission on the Future of the U.S. Space Program still make a lot of sense. These include designating Mars as the primary long-term objective of the human space program, most likely with the moon as a scientific base and stepping-off point, and getting on with developing a new heavy-lift launch capability (probably based on the shuttle's External Tank).

The cost of space transportation was, and is today, the most intransigent impediment to human space travel. The mission traffic models are sparse; the development costs large; the hazard of infant mortality of new vehicles daunting; and the arithmetic of discounted cost accounting and amortization intimidating. Thus, at least in my opinion, the true breakthrough in human spaceflight will occur only when space tourism becomes a reality. Yes, space tourism. There is a close parallel to the circumstance when World War II solved the chicken and egg problem of commercial air travel.

By space tourism I do not refer to a few wealthy individuals experiencing a few moments of exposure to high altitudes and zero g's. Rather, I mean a day or two on orbit for large numbers of people, peering through telescopes, taking photographs, eating, and exercising. There are, of course, those who would dismiss any such notion as fantasy—but what might the Wright Brothers have said if told that within the century the entire population of Houston would each day climb aboard an airplane somewhere in the US and complain that they had already seen the movie? Or Scott and Amundsen if informed that 14,000 people would visit

Antarctica each summer and 50 would live at the South Pole? Or James Wesley Powell if advised that 15,000 people would raft the Grand Canyon each year? Or Sir Edmund Hillary if told that 40 people would stand on top of Mount Everest one morning? In short, to be human is to be curious, and to be curious is to explore. And if there is any one thing we have learned about space pursuits, it is that they are a lot like heart surgery…if you are going to do any of it, it is wise to do a lot of it.

We have of course learned many other important things from the Space Shuttle Program. Those include how to integrate extraordinarily complex systems so as to operate in very unforgiving environments; that high traffic rates can and must be satisfied with reusability; that subsystems intended to be redundant are redundant only when they are independent; that long-term exposure to space can be tolerable for humans, at least in near-Earth orbit; and that the problems you expect (read tiles) can be overcome, while the problems you don't expect can overcome you (read seals and high-velocity, low-density fragment impacts). These and other lessons from the Space Shuttle human space programs have had a major effect on engineering discipline throughout the aerospace industry and much of the electronics industry as well.

There is a noteworthy parallel between the situation in which America found itself just after the Sputnik wake-up call and the circumstance that exists today just after the toxic mortgage wake-up call. In the former instance, much attention was turned to our nation's shortcomings in education, in producing future scientists and engineers, and in underinvestment in basic research. After Sputnik, the human space program became the centerpiece in an effort to reverse the above situation and helped underpin several decades of unparalleled prosperity. Today, the nation once again suffers these same ailments and once again is in need of "centerpieces" to focus our attention and efforts. And to this end nothing inspires young would-be scientists and engineers like space and dinosaurs—and we are noticeably short of the latter.

As for me, nothing other than the birth of my children and grandchildren has seemed more exciting than standing at the Cape and watching friends climb aboard those early shuttles, atop several hundred thousand gallons of liquid hydrogen and liquid oxygen, and then fly off into space.

My mother lived to be 105 and had friends who crossed the prairies in covered wagons. She also met friends of mine who had walked on the moon. Given those genes I may still have a shot at buying a round-trip ticket to take my grandchildren to Earth orbit instead of going to Disney World. And the Space Shuttle Program provided important parts of the groundwork for that adventure. All I need is enough "runway" remaining.

Global Community Through Space Exploration

John Logsdon, PhD
Former director of Space Policy Institute and professor, The George Washington University, and member of major space boards and advisory committees including the NASA Columbia Accident Investigation Board.

The Space Shuttle has been a remarkable machine. It has demonstrated the many benefits of operations in low-Earth orbit, most notably the ability to carry large pieces of equipment into space and assemble them into the International Space Station (ISS). Past research aboard the shuttle and especially future research on the ISS could have significant benefits for people on Earth. But research in low-Earth orbit is not exploration. In my view, it is past time for humans once again to leave low-Earth orbit and restart exploration of the moon, Mars, and beyond. President George W. Bush's January 2004 call for a return to the moon and then a journey to Mars and other deep space destinations is the policy that should guide US government human spaceflight activities in the years to come.

The 2004 exploration policy announced by President Bush also called for international participation in the US exploration initiative. The experience of the ISS shows the value of international partnerships in large-scale space undertakings. While the specifics of the ISS partnership are probably not appropriate for an open-ended exploration partnership, the spirit and experience of 16 countries working together for many years and through difficult challenges certainly is a positive harbinger of how future space exploration activities can be organized.

Since 2006, 14 national space agencies have been working together to chart that future. While the United States is so far the only country formally committed to human exploration, other space agencies are working hard to convince their governments to follow the US lead and join with the United States in a multinational exploration effort. One product of the cooperation to date is a "Global Exploration Strategy" document that was approved by all 14 agency heads and issued in May 2007. That document reflects on the current situation with words that I resonate with: "Opportunities like this come rarely. The human migration into space is still in its infancy. For the most part, we have remained just a few kilometers above the Earth's surface—not much more than camping out in the backyard."

It is indeed time to go beyond the "camping out" phase of human space activity, which has kept us in low-Earth orbit for 35 years. Certainly the United States should capitalize on its large investment in the ISS and carry out a broadly based program of research on this orbiting laboratory. But I agree with the conclusions of a recent White Paper prepared by

the Space, Policy, and Society Research Group at MIT: "A primary objective of human spaceflight has been, and should be, exploration." The Group argues that "Exploration is an expansion of human experience, bringing people into new places, situations, and environments, expanding and redefining what it means to be human." It is exploration, so defined, that provides the compelling rationale for continuing a government-funded program of human spaceflight.

I believe that the new exploration phase of human spaceflight should begin with a return to the moon. I think the reasons to go back to the moon are both that it is the closest place to go and it is an interesting place in its own right. We are not technologically ready for human missions to Mars, and the moon is a more understandable destination than just flying to a libration point in space or to a near-Earth object. The moon is like an offshore island of the planet Earth, and it only takes 3 days to get there. During the Apollo Program, the United States went to the surface of the moon six times between 1969 and 1972; the lunar crews explored only the equatorial region of the moon on the side that always faces the Earth. So we have never visited 85 to 90 percent of the moon's surface, and there are lots of areas yet to explore. The far side of the moon may be the best place in the solar system for radio astronomy. Most people who are looking at the issue now think that one of the poles of the moon, probably the South Pole, is a very interesting place scientifically, and that there may be resources there that can be developed for use in further space exploration. So the moon is an interesting object to study, and to do science from, and perhaps as a place to carry out economically productive activity.

The Space Shuttle has left us a legacy of exciting and valuable exploits in low-Earth orbit. But it is now time to go explore.

The Legacy of the "Space Shuttle"

Views of the Canadian Space Agency

The Space Transportation System; a.k.a. the "Space Shuttle"; is the vehicle that arguably brought Canada to maturity as a global space power. Canada was an early advocate in recognizing the importance that space could play in building the country. Initially, this was achieved through the development of small indigenous scientific satellites to study the Earth's upper atmosphere, beginning with Alouette, launched by NASA in 1962, which positioned Canada as the third nation, after the Soviet Union and the United States of America, to have its own satellite successfully operate in the harsh and largely unknown environment of space. The follow-on Alouette-II and ISIS series of satellites (1965 to 1971) built national competence and expertise and set the foundation for Canada's major contributions to the rapidly developing field of satellite communications (Anik series and Hermes), to using Earth Observation data to meet national needs, as well as to the development of signature technologies that were the basis of Canada's space industry (e.g., STEM* deployable systems, antennas). By the mid-1970s, however, Canada's emerging space program was at a crossroads: space communications were becoming commercialized, Canada was not yet ready to commit to the development of an Earth Observation Satellite, and no new scientific satellites or payloads were approved. This situation changed dramatically in 1974 when the Government of Canada approved the development of a robotic arm as a contribution to the Space Shuttle Program initiated by NASA two years earlier. This Shuttle Remote Manipulator System was designed to deploy and retrieve satellites from and to the Shuttle orbiter's payload bay, as well as support and move extra-vehicular astronauts and payloads within the payload bay. The first "Canadarm" was paid for by Canada and first flew on the second Shuttle flight in November 1981. Originally planned by NASA to be flown only occasionally, Canadarm has become a semi-permanent fixture due to its versatility and reliability, especially in support of extra-vehicular activities; i.e., spacewalks; and, more recently, as an essential element in the construction and servicing of the International Space Station and the detailed remote inspection of the Shuttle after each launch that is now a mandatory feature of each mission. Canadarm has become an important and very visible global symbol of Canadian technical competence, a fact celebrated in a recent 2008 poll of Canadians that identified the Canadarm as the top defining accomplishment of the country over the last century.

Returning to scientific endeavours, the Shuttle's legacy with respect to the space sciences in Canada was more circuitous. Towards the end of the 1970s, following the successful Alouette/ISIS series, Canada turned its attention to defining its next indigenous scientific satellite mission. As the merits of a candidate satellite called Polaire were debated, Canadian

**STEM—storage tubular extendible member*

scientists were encouraged to propose experiments in response to an Announcement of Opportunity released by NASA in 1978 to fly future missions on the Shuttle. This was during the heady days when a Shuttle mission was proposed to fly every couple of weeks with rapid change-out of payloads—the "space truck" concept—and with the possibility to utilize the formidable advantage of the Shuttle to launch and return scientific payloads leading to multiple mission scenarios for the same experiment or facility. Three Canadian proposals to fly sophisticated, complex experiments in the Shuttle payload bay were accepted by NASA—an Energetic Ion Mass Spectrometer to measure the charged particle environment; an ambitious topside-sounder experiment called Waves In Space Plasmas, a follow-on to the Alouette/ISIS program, to measure the propagation of radio waves through and within the Earth's atmosphere; and an optical measurement of atmospheric winds from space called Wide Angle Michelson Doppler Imaging Interferometer. Ironically, none of these three experiments flew on the Shuttle, all falling to the reality of a technically challenging program where missions every few months became the norm rather than every couple of weeks. However, the impetus to the Canadian scientific community of this stimulus through the infusion of new funds and opportunities enabled the community to flourish that, in turn, led to the international success of the space science program that is recognized today. Since 1978, Canada has successfully flown well over 100 scientific experiments in space with practically a 100% success rate based on the metric of useful data returned to investigators. The other contribution to science that Canada's partnership in the Shuttle Program provided was the possibility to develop new fields related to the investigation of how living systems and materials and fluids behave in space, especially the understanding of the effects of gravity and exposure to increased radiation. The possibility to fly such experiments on the Shuttle was reinforced in 1983 when, during the welcoming ceremony for the Shuttle Enterprise in Ottawa, the Administrator of NASA formally and publically invited Canada to fly two Canadians as payload specialists on future missions and the Minister of Science and Technology accepted on behalf of the Government of Canada. Canada responded by launching a nation-wide search for six individuals to join a newly formed Canadian Astronaut Program. In October 1984, now 25 years ago, Marc Garneau successfully flew a suite of six Canadian investigations called CANEX* that was put together in approximately 9 months—a development schedule that, today, would be practically impossible. Since that time, Canadian scientists have flown approximately 35 more experiments on the Shuttle, all producing excellent results for the scientific teams and significantly advancing our understanding of the way that living and physical systems behave in space.

**CANEX—Canadian experiments in space science, space technology, and life sciences*

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The Canadian astronaut program has been a remarkable success for Canada, not only in relation to the excellent support that the outstanding individuals who make up the corps have provided to the overall program but also by virtue of the visibility the individuals and missions have generated, especially within Canada. Canadian astronauts remain inspirational figures for Canadians, with every mission being widely covered in the media and appearances continuing to draw significant interest. It is a notable fact that after the Soviet Union/Russia and the USA, more Canadians have flown Shuttle missions than any other single country, fourteen such missions as of 2009.

In conclusion, it is fair to say that Canada's contribution to the Space Shuttle Program has dramatically changed the way that Canada participates in space activities. Over the past 35 years, since Canada initially decided to "throw its hat into the ring" in support of this new and revolutionary concept of a "space plane," Canada has become a leading player in global space endeavours. It can be argued credibly that Canada would not today be at the forefront of space science activities, space technology leadership, human spaceflight excellence and as a key partner in the International Space Station program if it had not been for the possibilities opened up by the Space Shuttle Program. A great debt of gratitude goes to those who saw and delivered on the promise of this program and to NASA for its generosity in believing in Canada's potential to contribute as a valuable and valued partner. Both gained enormously from this mutual trust and support and Canada continues to reap the benefits from this confidence in our program today. As we finish building and emphasize the scientific and technological use of the International Space Station, we look forward collectively to taking our first tentative steps as a species beyond our home planet. As we do so, the Space Shuttle will be looked upon as the vehicle that made all of this possible. Ad astra!

What is the Legacy of the Space Shuttle Program?

General John Dailey (USMC, Ret.)
Director
Smithsonian National Air and Space Museum

John Young, commander of the first space shuttle mission, pegged the shuttle perfectly as "a remarkable flying machine." Arising from the American traditions of ingenuity and innovation, the Space Shuttle expanded the range of human activity in near-Earth space. Serving as a cargo carrier, satellite deployment and servicing station, research laboratory, construction platform, and intermittent space station, the versatile shuttle gave scores of people an opportunity to live and do meaningful work in space. One of the most complex technology systems ever developed and the only reusable spacecraft ever operated, the shuttle was America's first attempt to make human spaceflight routine. For more than 30 years and more than 125 missions, the Space Shuttle kept the United States at the forefront of spaceflight and engaged people here and around the world with its achievements and its tragedies. The experience gained from the Space Shuttle Program will no doubt infuse future spacecraft design and spaceflight operations for years to come.

Inspiring Generations

Leah Jamieson, PhD
Dean of the College of Engineering
Purdue University

The space race, set in motion by the 1957 launch of Sputnik and reaching its pinnacle with the Apollo 11 landing on the moon, is credited with inspiring a generation of engineers. In the United States, Congress in 1958 provided funding for college students and improvements in science, mathematics, and foreign-language instruction at elementary and secondary schools. Math and science curricula flourished. University enrollment in science and engineering programs grew dramatically. For over a decade, not only engineers themselves, but policy makers and the public genuinely believed that the future depended on engineers and scientists and that education would have to inspire young people to pursue those careers.

Almost as if they were icing on the cake, innovation and technology directly or indirectly inspired by the space program began to shape the way we live and work: satellite communications, satellite navigation, photovoltaics, robotics, fault-tolerant computing, countless specialty materials, biomedical sensors, and consumer products all advanced through the space program.

Over the 30-year era of the Space Shuttle, it sometimes seems that we've come to take space flight for granted. Interest in technology has declined: bachelor's degrees awarded in engineering in the US peaked in 1985. Reports such as the Rising Above the Gathering Storm (National Academies Press, 2007) urge a massive improvement in K-12 math, science, and technology education in order to fuel innovation and ensure future prosperity. Engineering educators are looking to the National Academy of Engineering's "grand challenges" (NAE, 2008) not only to transform the world, but to inspire the next generation of students.

Has space exploration lost the ability to inspire? I don't think so. Over the past five years, I have talked about engineering careers with more than 6,000 first-year engineering students at Purdue University, asking them what engineers do and why they are studying engineering. Not a session has gone by without at least one student saying "I'm studying engineering because I want to be an astronaut." Purdue students come by this ambition honestly: 22 Purdue graduates have become astronauts, including Neil Armstrong, the first man to walk on the moon, and Eugene Cernan, the last—or as he prefers to say, "the most recent." A remarkable 18 of the 22 (all except Armstrong, Cernan, Grissom, and Chaffee) have flown Space Shuttle missions, for a total of 56 missions. Inspiration lives.

I've also talked with hundreds of IEEE* student leaders in Europe, Africa, Latin America, and Asia, asking them, as well as the Purdue undergrads, what their generation's technological legacy might be. In every session on every continent, without exception, students have talked about space exploration. Their aspirations range from settlements on the moon to human missions to Mars. These students, however, add a layer of intent that goes beyond the simple "we'll go because it's there." They talk about extraterrestrial settlements as part of the solution to Earth's grand challenges of population growth, dwindling resources, and growing poverty. More nuanced, perhaps, and more idealistic—but again, evidence of the power to inspire.

These students are telling us that space exploration is about dreaming, but it's also about doing. This isn't a new message, but it's one that is worth remembering. It's unlikely that the inspiration for the next generation of engineers will come from one galvanizing goal, as it did in the Sputnik and Apollo era. Yet, space exploration has the exquisite ability to stretch both our physical and spiritual horizons, combined with the proven ability to foster life-changing advances in our daily lives. This combination ensures that human exploration of space will continue to be a grand challenge that inspires. As the Space Shuttle era draws to a close, it's a fitting time to celebrate the Space Shuttle Program's achievements, at the same time that we ask today's students—tomorrow's engineers—"what's next?" I believe that we'll be inspired by their answers.

**The Institute of Electrical and Electronics Engineers*

The Legacy of the Space Shuttle

Michael Griffin, PhD*
NASA administrator, 2005-2009

When I was asked by Wayne Hale to provide an essay on the topic of this paper, I was as nearly speechless as I ever become. Wayne is a former Space Shuttle Program Manager and Shuttle Flight Director. In the latter capacity, he holds the record—which cannot now be broken—for directing shuttle ascents and re-entries, generally the most dynamic portion of any shuttle mission. His knowledge of the Space Shuttle system and its history, capabilities, and limitations is encyclopedic.

In contrast, I didn't work on the shuttle until, on April 14, 2005, I became responsible for it. Forrest Gump's mother's observation that "life is like a box of chocolates; you never know what you're going to get," certainly comes to mind in this connection. But more to the point, what could I possibly say that would be of any value to Wayne? But, of course, I am determined to try.

The first thing I might note is that, whether I worked on it or not, the shuttle has dominated my professional life. Some connections are obvious. In my earlier and more productive years, I worked on systems that flew into space aboard shuttle. As I matured—meaning that I offered less and less value at higher and higher organizational levels—I acquired higher level responsibility for programs and missions flying on shuttle. I first met Mike Coats, director of the Johnson Space Center, through just such a connection. Mike commanded STS-39, a Strategic Defense Initiative mission for which I was responsible. Later, as NASA Chief Engineer in the early '90s, I led one of the Space Station Freedom redesign teams; the biggest factor influencing station design and operations was the constraint to fly on shuttle.

My professional connections with the Space Shuttle are hopelessly intertwined with more personal ones. Many of the engineers closest to me, friends and colleagues I value most highly, have worked with shuttle for decades. And, over the years, the roster of shuttle astronauts has included some of the closest friends I have. A hundred others have been classmates and professional colleagues, supervisors and subordinates, people I see every day, or people I see once a year. Speaking a bit tongue-in-cheek, I once told long-time friend Joe Engle that I loved hearing his stories about flying the X-15 because, I said, they were different; my other friends had all flown on shuttle.

From time to time, I make it a point to remember that two of them died on it.

Most of us have similar connections to the Space Shuttle, no matter what part of the space business in which we have worked. But the influence of the shuttle on the American

* Written in 2009 while serving as NASA administrator.

space program goes far beyond individual events, or even their sum, because the legacy of the Space Shuttle is a case where the whole truly is more than the sum of the parts.

Because of its duration at the center of human spaceflight plans and activities, because of the gap between promise and performance, because of the money that has been spent on it, because of what it can do and what it cannot do, because of its stunning successes and its tragic failures, the Space Shuttle has dominated the professional lives of most of us who are still young enough to be working in the space business. I'm 59 years old as I write this, and closer to retirement than I would like to be. Anyone my age or younger who worked on Apollo had to have done so in a very junior role. After Apollo, there were the all-too-brief years of Skylab, the single Apollo-Soyuz mission, and then—Space Shuttle. So, if you're still working today and spent any time in manned spaceflight over the course of your career, you worked with shuttle. And even if you never worked in human spaceflight, the shuttle has profoundly influenced your career.

So, as the shuttle approaches retirement, as we design for the future, what can we learn from having built and flown it, loved and feared it, exploited and been frustrated by it?

If the shuttle is retired by the end of 2010, as presently planned, we will have been designing, building, and flying it for more than 4 decades, four-fifths of NASA's existence. This is typical; aerospace systems normally have very long life cycles. It was Apollo that was an aberration. We must remember this as we design the new systems that will, one day, be commanded by the grandchildren of the astronauts who first fly them. We must resist making compromises now, just because budgets are tight. When a system is intended to be used for decades, it is more sensible to slip initial deployment schedules to accommodate budget cuts than to compromise technical performance or operational utility. "Late" is ugly until you launch; "wrong" is ugly forever.

The shuttle is far and away the most amazingly capable space vehicle the world has yet seen, more so than any of us around today will likely ever see again. Starting with a "clean sheet of paper" less than a decade after the first suborbital Mercury flight, its designers set—and achieved—technological goals as far beyond Apollo as Apollo was beyond Mercury. What it can do seems even now to be the stuff of science fiction.

But it is also operationally fragile and logistically undependable. Its demonstrated reliability is orders of magnitude worse than predicted, and certainly no better than the expendable vehicles it was designed to replace. It does not degrade gracefully. It can be flown safely and well, but

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only with the greatest possible attention to every single detail, to the consequences both intended and unintended of every single decision made along the path to every single flight. The people who launch it and fly it are the best engineers, technicians, and pilots in the world, and most of the time they make it look easy. It isn't. They work knowing that they are always one misstep away from tragedy.

It was not intended to be this way; the shuttle was intended to be a robust, reliable vehicle, ready to fly dozens of times per year at a lower cost and a higher level of dependability than any expendable vehicle could ever hope to achieve. It simply didn't happen. What shuttle does is stunning, but it is stunningly less than what was predicted.

If it is true that "satisfaction equals results minus expectations," and if ultimately we have been unsatisfied, maybe where we went wrong was not with the performance achieved, but with the goals that were set. What if we had not tried for such an enormous technological leap all in one step? What if the goal had been to build an experimental prototype or two, fly them, and learn what would work and what was not likely to? Then, with that knowledge in hand, we could have proceeded to design and build a more operationally satisfactory system. What if we had kept the systems we had until we were certain we had something better, not letting go of one handhold until possessed of another?

That we did not, of course, was not NASA's fault alone. There was absolutely no money to follow the more prudent course outlined above. After the cancellation of Apollo by President Nixon, the NASA managers of the time were confronted with a cruel choice: try to achieve the goals that had been set for the shuttle, with far less money than was believed necessary, or cease US manned spaceflight. They chose the former, and we have been dealing with the consequences ever since. That they were forced to such a choice was a failure of national leadership, hardly the only one stemming from the Nixon era. But the lesson for the future is clear: in the face of hard choices, technical truth must hold sway, because it does so in the end, whether one accepts that or not.

I will end by commenting on the angst that seems to accompany our efforts to move in an orderly and disciplined manner to retire the shuttle. In my view we are missing the point, and maybe more than one point.

First, the shuttle has been an enormously productive step along the path to becoming a spacefaring civilization. But it does not lie at the end of that path, and never could have.

It was an enormous leap in human progress. The shuttle wasn't perfect, and we will make more such leaps, but none of them will be perfect, either.

Second, even if the shuttle had accomplished perfectly that which it was designed to do, we must move on because of what it cannot do and was never designed to do. The shuttle was designed to go to low orbit, and no more. NASA's funding is not such that we can afford to own and operate two human spaceflight systems at the same time. It never has been. There were gaps between Mercury and Gemini, Gemini and Apollo, Apollo and Space Shuttle. There will be a gap between Space Shuttle and Constellation*. So, if we can have only one space transportation system at a time—and I wish wholeheartedly that it were otherwise—then in my opinion it must be designed primarily to reach beyond low-Earth orbit.

If we are indeed to become a spacefaring civilization our future lies, figuratively, beyond the coastal shoals. It lies outward, beyond sight of land, where the water is deep and blue. The shuttle can't take us there. Our Constellation systems can.

So, yes, we are approaching the end of an era, an era comprising over 80% of NASA's history. We should recognize and celebrate what has been accomplished in that era. But we should not be sad, because by bringing this era to an end, we are creating the option for our children and grandchildren to live in a new and richer one. We are creating the future that we wanted to see.

**Constellation refers to the NASA program designed to build the capability to leave low-Earth orbit.*